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Modern non-destructive methods for testing and quality control of asphalt road pavements and application of ground-penetrating radar in Bulgaria

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Summary
This paper presents modern field methods for quality control and condition assessment of asphalt pavements, with particular emphasis on the application of ground-penetrating radar (GPR) for determining asphalt layer thickness. Good practices and methodological recommendations for conducting GPR-based investigations are proposed. An overview of projects carried out in Bulgaria in recent years is provided, along with selected results from their implementation.

Introduction

Quality control in road construction is of primary importance for the durability and safe operation of road infrastructure. It is carried out both during construction activities and after their completion (Mihaylov & Hristov 2005). Methods for testing and controlling asphalt pavements are applied to a wide range of tasks, mainly related to assessing technical condition, load-bearing capacity, surface evenness, skid resistance, compaction level, and pavement thickness (Angelova 2008).
The traditional approach involves extracting cores from the pavement and analyzing them in laboratory conditions. Unlike these destructive methods, modern field techniques allow for on-site investigations with minimal or no damage to the pavement structure.

Field Methods for Determining the Parameters of Asphalt Pavements

Modern road engineering practice relies on a wide range of field methods to evaluate the key performance indicators of asphalt pavements. Among the most commonly applied approaches are both non-destructive and semi-destructive techniques, each with its specific application.
One of the most established methods is the Falling Weight Deflectometer (FWD) test, where an impulse load simulates the effect of a passing vehicle. The resulting deflections are recorded by sensors, and from these measurements, the bearing capacity and elastic modulus of the pavement structure are determined. This test is a primary tool for diagnostics and rehabilitation planning.
Another widely used method is the nuclear density gauge test, applied for determining bulk density and moisture content of compacted asphalt mixtures. It uses a radioactive source and a detector that registers the gamma radiation passing through the material, enabling fast and non-destructive measurements. As a safer alternative, the non-nuclear Pavement Quality Indicator (PQI), based on electromagnetic impulses in the microwave range, is often applied.
For evaluating serviceability, measuring surface roughness—mainly using the International Roughness Index (IRI)—is essential. Laser scanners mounted on vehicles provide data directly related to ride comfort and traffic safety. This approach is used both for certifying newly built road sections and for continuous monitoring.
An important safety-related parameter is pavement skid resistance, determined through various Skid Resistance Tests. These are designed to establish the friction coefficient, particularly under wet conditions and in high-risk areas such as pedestrian crossings or sharp curves.
A significant contribution to modern pavement assessment comes from Ground Penetrating Radar (GPR). By emitting high-frequency radio waves into the pavement, it gathers information about the thickness and condition of individual layers, as well as the presence of voids or moisture. The technique is quick, non-destructive, and particularly suitable for large-scale surveys (Wang et al. 2022).
To determine deformation characteristics of pavements, the Plate Load Test (PLT) and its portable variant, the Light Weight Deflectometer (LWD), are frequently used. These are particularly applicable for investigating subgrade and base layers, especially in areas with limited access.

With the advancement of technology, infrared thermography (IR thermography) is increasingly applied. It is used to monitor temperature distribution during asphalt placement, enabling early detection of cold joints and preventing uneven compaction. Additionally, infrared thermography is applied in post-construction inspections of existing pavements. Using drones or handheld cameras, areas of inadequate compaction, delamination, or local defects around patches and joints can be detected as thermal anomalies (Vyas et al. 2020). This broadens the scope of the method as a fast, efficient, and non-destructive tool for quality control during both construction and operation phases.
Finally, GPS and GIS technologies are gaining wider application for geospatial registration of measurement results. Their integration into Pavement Management Systems (PMS) facilitates data analysis and long-term planning of maintenance activities.
Despite the advances in non-destructive methods, traditional core sampling remains the gold standard for verifying actual thickness and internal structure of pavements. Laboratory testing of cores provides high accuracy, albeit at the cost of localized damage. Often, core sampling is combined with non-destructive techniques such as GPR, which reduces the number of cores required by extrapolating calibration results across wider sections.

Detailed Overview of GPR Surveys for Determining Asphalt Pavement Thickness

Ground Penetrating Radar (GPR) is one of the most effective modern methods for non-destructive investigation of road pavements. It employs high-frequency electromagnetic waves transmitted into the pavement, which are reflected at the boundaries between different layers. Analysis of the reflected signals makes it possible to determine the thickness and condition of the structural layers, as well as to identify areas of reduced density, voids, or increased moisture content.
GPR surveys can be conducted using either vehicle-mounted equipment or manually operated systems. Vehicle-mounted radar systems are suitable for rapid assessment of long pavement sections, providing continuous radar profiles at speeds of up to several tens of kilometers per hour. This technology is particularly valuable for systematic inspections, certification of newly constructed road segments, or rehabilitation planning. Hand-pushed radar systems, on the other hand, are more appropriate for detailed local studies and for use in areas with limited access—such as intersections, bridge decks, or small repair sites. They deliver high-resolution data and allow precise measurements of individual problem areas.
Comparisons between GPR survey results and extracted core samples demonstrate strong correlation, with deviations typically within 2–10% of laboratory-derived thickness values (McGrath et al. 2013), confirming the method's reliability. In addition, modern software solutions allow the processing and integration of GPR data into GIS platforms, facilitating spatial analysis and supporting engineering decision-making.
As a result, GPR is increasingly recognized as a vital tool for modern pavement monitoring and diagnostics, offering speed, high informational value, and non-destructive operation.

Methodological Approach for Investigating Asphalt Pavement Thickness Using Core Samples and Multi-Frequency GPR Surveys

For reliable determination of the thickness and structure of asphalt pavements, a combined approach is applied, integrating core sampling with ground-penetrating radar measurements at different frequencies. Core samples are taken at selected points along the road alignment to serve as reference data. At these same locations, transverse GPR profiles are collected using a high-frequency antenna (800–1600 MHz). The radar results are then calibrated against the core-derived thicknesses through iterative adjustment of dielectric parameters and electromagnetic wave velocity. The outcome of this calibration is illustrated in Figure 1.
In parallel, the road section under investigation is surveyed along its full length with a medium-frequency antenna (400–800 MHz), ensuring that the intersections between longitudinal profiles, transverse profiles, and core sampling points are properly marked on the radargrams.
Data processing requires adherence to the following sequence: calibration of high-frequency profiles using core samples → calibration of medium-frequency profiles at their intersections with the already calibrated transverse profiles. The order of the fieldwork itself, however, may vary, provided that the intersection points between the different types of surveys are predetermined and accurately implemented in the field.
The proposed methodology was developed by the authors using a hand-held StructureScan Mini system (1600 MHz, GSSI Inc.) and a MALÅ X3M system with a medium-frequency 800 MHz antenna mounted on a cart.
This approach is most suitable for relatively short sections (up to 2 km), but due to the lack of an available vehicle-mounted GPR system, it has also been applied to longer road stretches divided into smaller segments.

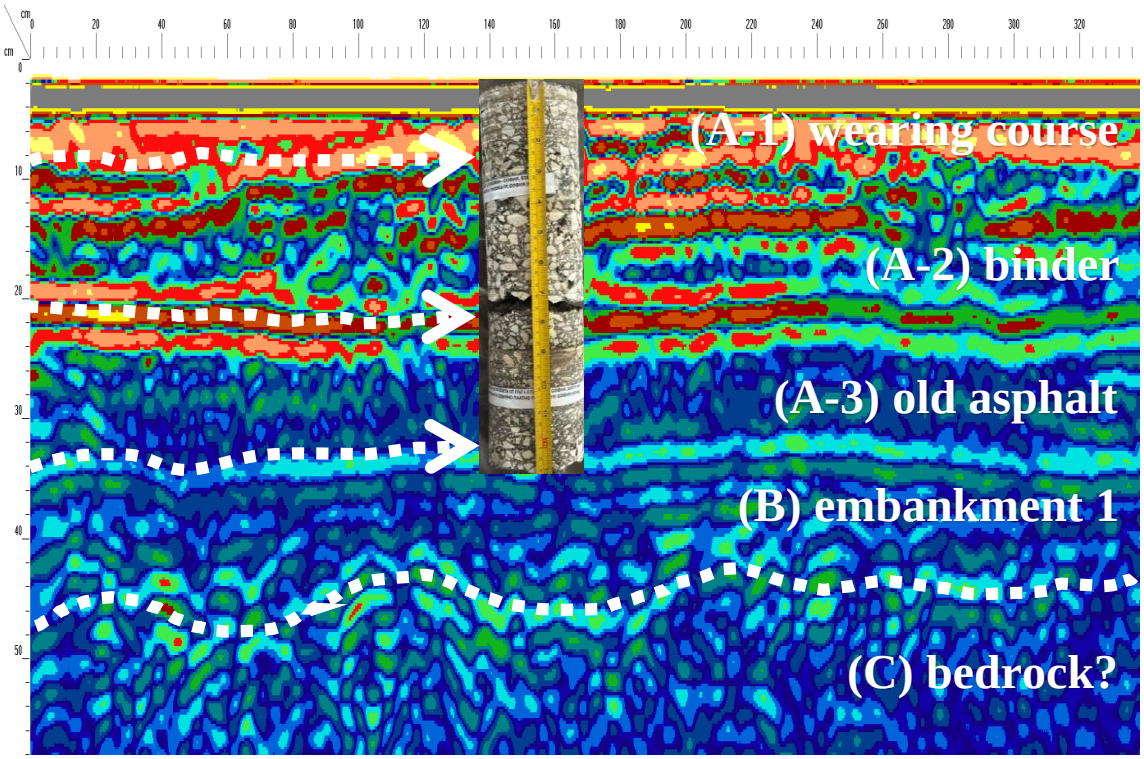


Figure 1. Image of a core sample taken from Road I-3 Sofia–Pleven near the village of Telish, superimposed on a transverse high-frequency GPR profile of the road, with interpretation

Case Studies of GPR Applications on Asphalt Pavements in Bulgaria

In recent years, the practical application of ground penetrating radar for assessing the thickness and condition of asphalt pavements in Bulgaria has experienced a certain upsurge. The technology has been employed both for quality control of newly constructed sections and for inspections following rehabilitation or under extraordinary circumstances.

One of the first widely reported cases was the survey of the Northern Speed Tangent in Sofia (2023), where GPR was used to verify the actual thickness of the pavement after concerns arose about possible deviations from the design specifications (Tzankov 2023). In parallel, detailed vehicle-based GPR investigations were conducted by experts from the University of Zagreb (ETCP 2023).

In the same year, surveys were also carried out along the Lyutidol–Botevgrad route (Road III-161) with a total length of 33 km, commissioned for quality control of rehabilitation works. Data were collected down to a depth of 2 m, again by a team from the University of Zagreb (ETCP 2023).

In 2024, GPR was applied to the inspection of newly laid pavements within the large-scale infrastructure project Speed Road I-1 “Vidin–Botevgrad,” LOT 2 (Lyutidol–Mezdra section). Nearly 7.8 km were surveyed with the aim of providing independent verification of asphalt layer thicknesses and the condition of the pavement structure down to the subgrade (Tzankov and Stefanov 2024).

In 2025, near the village of Telish (Road I-3), a GPR survey was conducted in connection with a forensic investigation following a severe traffic accident. The study covered a 600-meter section, aiming to determine the actual pavement thickness and structural integrity (Tzankov and Stefanov 2025). In the same year, additional surveys were performed along Lyutidol–Mezdra (Road I-1, LOT 2) over six sections with a combined length of about 6 km, focusing on verification of pavement construction and compliance with design requirements (Tzankov and Stefanov 2025).

Conclusions

Quality control of road pavements is crucial for ensuring their durability and safe operation. Alongside classical laboratory techniques, modern practice increasingly employs non-destructive technologies that enable rapid and precise assessment of pavement conditions. Ground penetrating radar has become a key tool for determining the thickness and condition of structural layers, particularly when combined with core sampling for calibration and improved accuracy. The proposed methodology, integrating high-frequency and medium-frequency GPR measurements with core drilling, demonstrates an effective approach for reliable interpretation

and modeling of pavement structures, applicable to both short sections and longer road stretches. Field case studies from Bulgaria in recent years illustrate the growing confidence in these technologies and their practical value for independent quality control, diagnosis of problematic areas, and rehabilitation planning. In addition, infrared thermography and other modern methods complement these capabilities by supporting defect detection and prevention. Altogether, an integrated approach is emerging, in which the combination of multiple techniques ensures higher reliability of evaluations and more effective pavement asset management.

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Съвременни безразрушителни методи за изследване и качествен контрол на асфалтови пътни настилки и приложение на георадара в България

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Ключови думи: безразрушителни изпитвания, асфалтова настилка, контрол на качеството, георадар

Резюме

В статията са представени съвременни полеви методи за контрол на качеството и оценка на състоянието на асфалтови пътни настилки. Акцент е поставен върху прилагането на георадар за определяне на дебелината на асфалтовите пластове. Предложени са добри практики и препоръки за методическа последователност при провеждането на подобни изследвания с използване на георадар. Направен е обзор на реализирани през последните години проекти в България, като са представени и резултати от тяхното приложение.